U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fuel Cycle Research and Development

Evaluation & Screening - Metrics

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Fuel Cycle Evaluation and Screening
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We Have Defined the Criteria - For Application at the Fuel Cycle Level

- **Nuclear Waste Management** – Management of the radioactive wastes requiring disposal, including any spent nuclear fuel (SNF), high-level waste (HLW), excess uranium (RU/DU) and low-level waste (LLW).
- **Proliferation Risk** – The risk of a nation ("host-state") using civilian nuclear activities (such as materials, facilities, or technologies) to obtain materials usable in nuclear weapons.
- **Nuclear Material Security Risk** – The risk of nuclear materials being diverted from civilian nuclear activities by "sub-national" or terrorist groups for use in nuclear weapons or radioactive dispersal devices.
- **Safety** – The challenge of assuring the safe implementation of nuclear energy and compliance with existing and future safety requirements.
- **Financial Risk and Economics** – The economics (cost factors) of the mature deployed system, including siting, construction, and operation of facilities, including consideration of the financial risk.
- **Environmental Impact** – The impact to the environment from all activities related to the civilian nuclear energy system.
- **Resource Utilization** – The natural fuel resources required per unit of power production from the civilian nuclear energy system.
- **Development and Deployment Risk** – The challenge of bringing to maturity the required technologies for a civilian nuclear energy system, including the time and cost required for successful research and development, and the ability to deploy licensable systems.
- **Institutional Issues** – The availability or ability to create the supporting infrastructure to deploy a civilian nuclear energy system, including the industrial infrastructure, qualified personnel, and the existence of regulations for licensing.

Development of Metrics

- **The 9 high-level criteria were given (by DOE) to make the evaluation and screening relevant to important nuclear energy issues - not to make it easy to develop metrics.**
  - The criteria are not independent
  - The criteria relate to nuclear energy issues that often are dependent on the technology used and the details of how those technologies are implemented. These are often not relevant at the fuel cycle level. Such issues will become more relevant following fuel cycle level screening when R&D needs and implementation pathways are considered.

- **Draft metrics have been developed through an iterative process.**
  - Review of metrics from prior fuel cycle and technology studies.
  - Discussion and input from other campaigns where appropriate.
  - Testing of proposed metrics to check adequacy and implementation.

This workshop is another step in the process – to seek feedback from stakeholders.

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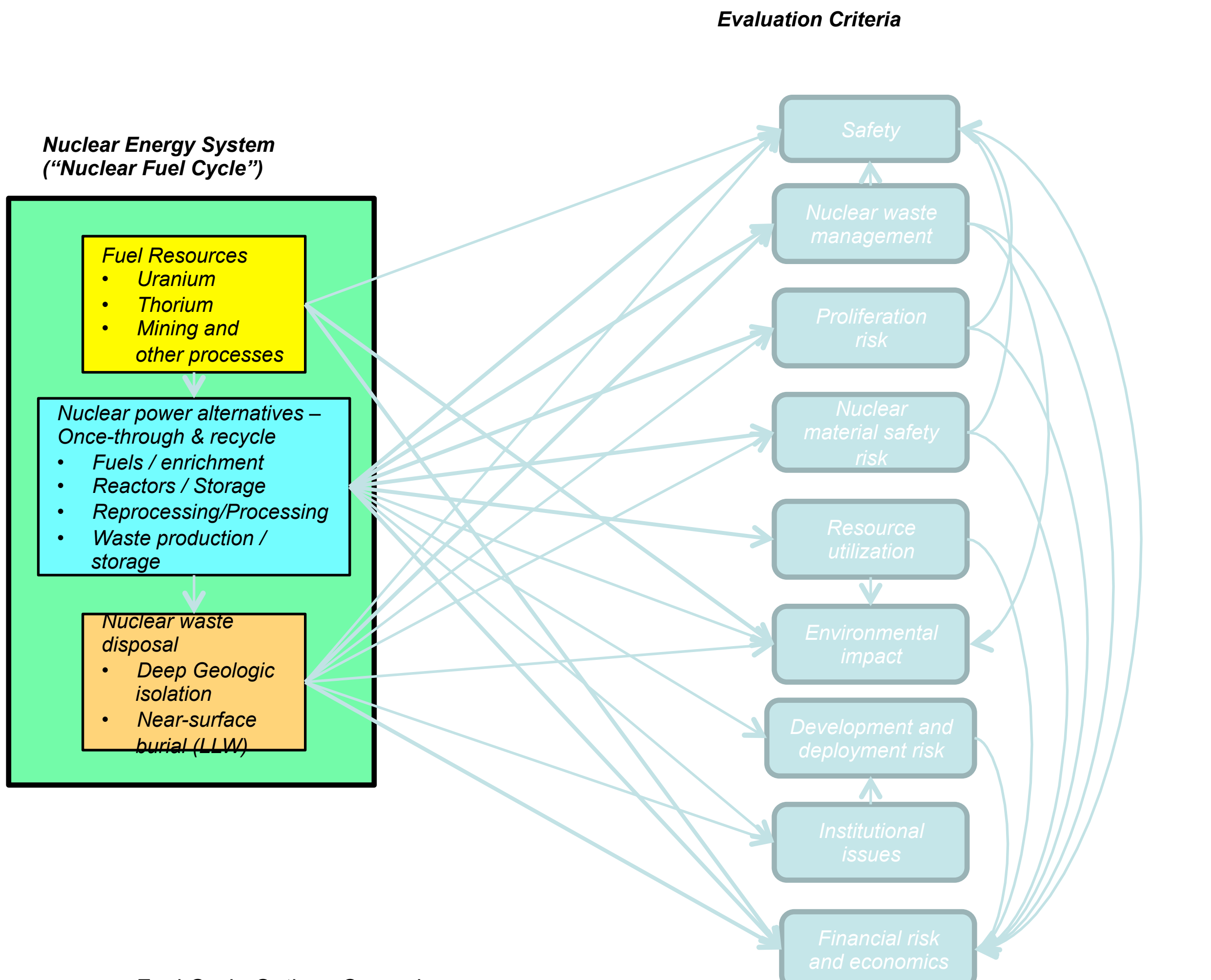
Nuclear Energy

Nuclear Energy System – Criteria Influences

- **There is interdependence between fuel cycle features and the criteria, and between the criteria themselves.**



Criterion – Nuclear Waste Management

- **Nuclear Waste Management** – Management of the radioactive wastes requiring disposal, including any spent nuclear fuel (SNF), high-level waste (HLW), excess uranium (RU/DU) and low-level waste (LLW).
- **About this Criterion:** This criterion focuses on the radioactive waste streams from the nuclear energy system. The largest concern is management of SNF and/or the HLW from processing of used fuel. Additional concerns include management of LLW, and excess recovered uranium (RU) from processing and depleted uranium (DU) from enrichment.
- **Key questions about nuclear waste management:**
  - How much radioactive waste is created?
  - How dangerous is it?
  - What do we do with it?

Nuclear Waste Management Metrics

- **What is Included:** This criterion addresses the radioactive waste streams - SNF, HLW, RU/DU, LLW.
- **What is Not Included:** It does not address disposal cost, operational safety, non-radioactive emissions, or releases incidental to operations – as these are addressed in other criteria. It does not include mine tailings.
- **Assumptions:**
  - To evaluate waste management at the fuel cycle level, it is not appropriate to assess waste management implementation details such as repository design, location, host environment, etc. These features are being studied by the Used Fuel Disposition campaign, and will be important in future decisions on the waste management implementation pathway.
  - For this evaluation, GTCC is included with LLW.
  - TRU waste is considered a defense waste stream and not included here.
  - Mine tailings are considered under environmental safety.
  - Other WM ‘issues’ are reflected in other criteria: Safety, Cost, Environment …

Nuclear Waste Management Metrics

- **Draft Metrics (5):**
  - Mass of SNF+HLW disposed per energy generated *(t/GWe-yr)*
  - Activity of SNF+HLW (@ 100 years) per energy generated *(MCi/GWe-yr)*
  - Activity of SNF+HLW (@100K years) per energy generated *(MCi/GWe-yr)*
  - Mass of DU/RU disposed per energy generated *(t/GWe-yr)*
  - Volume of LLW per energy generated *(m^3/GWe-yr)*
- **Rationale:**
  - These metrics focus on waste stream quantity and type, which are fuel cycle level characteristics. Three focus on SNF/HLW – with the greatest hazards, one focuses on 'how much' (mass), and two focus on both 'hazard and quantity' (activity) one during operational time and one for geologic isolation time. One each measures LLW and RU/DU.
  - The three waste types are selected by common characteristics and disposal pathway:
    - *SNF/HLW contain the high-activity fission products and any actinides that are disposed of, and are typically sent to deep geologic isolation.*
    - *RU/DU are primarily uranium, a waste stream that becomes more hazardous with time (as daughter products decay in) and may be managed with intermediate isolation.*
    - *LLW is a larger-volume, lower-activity waste stream and is typically disposed in near-surface isolation.*

Nuclear Waste Management Metrics

- **Information to address the metric:**
  - Waste stream material flow and SNF/HLW isotopic data will be calculated.
  - For HLW waste, a representative disposal form mass will be used.
  - Relative volume of LLW will be estimated for common fuel cycle features. The EST will assess unique fuel cycle features for relative LLW volume potential.

Criterion – Proliferation Risk

- **Proliferation Risk** – The risk of a nation ("host-state") using civilian nuclear activities (such as materials, facilities, or technologies) to obtain materials usable in nuclear weapons.
- **About this Criterion:** While the evaluation and screening process is for U.S. fuel cycles, this criterion focuses on fuel cycle characteristics that would be of most concern for proliferation risk in a non-nuclear-weapons state. Many important issues for proliferation risk depend on technology and implementation details and are not relevant at the fuel cycle level.
- **Key questions about proliferation risk at the fuel cycle level include:**
  - Does the fuel cycle inherently use material attractive for proliferation?
  - Does the fuel cycle inherently use technology attractive for misuse for proliferation?

Proliferation Risk Metrics

- **What is Included:** This criterion addresses the proliferation risk of materials used within a fuel cycle, and the potential for misuse of fuel cycle technology.
- **What is Not Included:** It does not address details of technology, safeguards, cost, operations or implementation. It does not include material security.
- **Assumptions:**
  - This metric is not predicated on any specific size of the nuclear energy enterprise.
  - Proliferation resistance is not the same as proliferation risk. Resistance includes a variety of implementation details not relevant at the fuel cycle level.
  - This is not a proliferation risk assessment.
  - Any nuclear energy system, and thus any fuel cycle - has proliferation risk.
  - Proliferation risk is inherently an ambiguous characteristic, and typically the location and host intent dominate other issues.
  - The characteristics of materials and technologies used within a fuel cycle may inform on proliferation risk to some extent, but may be dominated by implementation details in practice. Thus, fuel cycle level proliferation risk may prove to be a secondary issue (at the fuel cycle level).

Proliferation Risk Metrics

- **Metrics (3): Material Attractiveness as calculated by FOM_1 at Sensitive Points of the Fuel Cycle:**
  - Maximum FOM_1 (nominal fuel cycle material)
  - Maximum FOM_1 (material with misuse of technology included in the fuel cycle)
  - Maximum FOM_1 (material with clandestine use of any technology)
- **Rationale:**
  - The first metric addresses the proliferation attractiveness of materials as they nominally exist within the stated fuel cycle, without further processing. This addresses direct use of fuel cycle material.
  - The second metric addresses the proliferation attractiveness of materials that are used in the fuel cycle assuming intentional misuse of technologies that are explicitly included in the stated fuel cycle. This addresses development of clandestine facilities based on fuel cycle technologies, and diversion of materials.
  - The third metric addresses the proliferation attractiveness of materials that are used in the fuel cycle assuming clandestine development of technologies that are not explicitly included in the stated fuel cycle. This addresses clandestine development of technology beyond the stated fuel cycle.

Proliferation Risk Metrics

- **Information to address the metric:**
  - The potentially sensitive points of the Evaluation Group fuel cycle will be identified within a standard framework for common fuel cycle features. Unique features will be assessed by the EST for potential sensitive points.
    - *1 - Material characteristics as nominally used in the fuel cycle will be used for FOM_1 evaluations, and maximum value used.*
    - *2 - Material characteristics considering maximum misuse of technologies included in the fuel cycle will be used for FOM_1 evaluations, and maximum value used.*
    - *3 - Material characteristics considering maximum clandestine use of any fuel cycle technology (whether it is inherent in the Evaluation Group or not) will be used for FOM_1 evaluations, and maximum value used.*
  - Processes and facilities will be specified for the fuel cycle to identify sensitive points, and material characteristics will be calculated.

Criterion – Nuclear Material Security Risk

- **Nuclear Material Security Risk** – The risk of nuclear materials being diverted from civilian nuclear activities by "sub-national" or terrorist groups for use in nuclear weapons or radioactive dispersal devices (RDD).
- **About this Criterion:** While typical evaluation for nuclear material security includes physical protection requirements and methods, these are primarily specific to implementation details. At the fuel cycle level, the primary indicator of material security risk focuses on the characteristics of materials used.
- **The key question about material security risk includes:**
  - What are hazardous characteristics of materials used within the fuel cycle?

Nuclear Material Security Metrics

- **What is Included:** This criterion addresses the risk of materials that might be diverted.
- **What is Not Included:** It does not address details of technology details, safeguards, cost, operational or implementation. It does not specifically include proliferation concerns. It is not predicated on any specific size of the nuclear energy enterprise.
- **Assumptions:**
  - This metric is not predicated on any specific size of the nuclear energy enterprise.
  - Of the variety of measures for material hazard, none is clearly the definitive choice for use at the fuel cycle level, and the various measures are correlated.
  - At the fuel cycle level, quantities of material at any given point are a function of design and implementation details. Only material characteristic is fundamental to the fuel cycle.
  - The characteristics of materials used within a fuel cycle may inform on material security risk to some extent, but may be dominated by implementation details in practice. Thus, fuel cycle level material security risk may prove to be a secondary issue.

Nuclear Material Security Risk Metrics

- **Metrics (1): Material Attractiveness as calculated by FOM_1 at Sensitive Points of the Fuel Cycle:**
  - Maximum FOM_1 (nominal fuel cycle material)
- **Rationale:**
  - This metric addresses the intrinsic hazard of materials as they nominally exist within the stated fuel cycle, without further processing. This addresses direct theft of fuel cycle material.
- **Information to address the metric:**
  - The potentially sensitive points of the Evaluation Group fuel cycle will be identified within a standard framework for common fuel cycle features. Unique features will be assessed by the EST for potential sensitive points.
    - *1 - Material characteristics as nominally used in the fuel cycle will be used for FOM_1 evaluations, and maximum value used.*
  - Processes and facilities will be specified for the fuel cycle to identify sensitive points and material characteristics will be calculated.

Criterion – Safety

- **Safety** – The challenge of assuring the safe implementation of nuclear energy and compliance with existing and future safety requirements.
- **About this Criterion:** The issue of nuclear energy safety is often focused on severe accident risk and consequence. However, it is assumed that all facilities used in a fuel cycle will be designed, built, operated and regulated to meet safety standards. Most of the issues considered in both operational safety and severe accidents are technology, design and implementation specific. There is little about a fuel cycle that directly informs on safety. At the fuel cycle level, the primary indicators of safety focus on the potential safety hazards and the relative challenge to manage those hazards.
- **The key question about safety at the fuel cycle level is:**
  - What safety hazards exist, and what is the relative challenge in managing those hazards? (Relative to the reference case.)

Safety Metrics

- **What is Included:** This criterion focuses on challenges for safety and management of those challenges.
- **What is Not Included:** It does not address technology details, design, existence of regulations, or other implementation details. It is not predicated on any specific size of the nuclear energy enterprise.
- **Assumptions:**
  – It is assumed that all facilities used in a fuel cycle will be designed, built, operated and regulated to meet safety standards.

Safety Metrics

- **Metric (1):**
  - Relative Safety Management Challenge for all facilities and processes
  - *Note: Secondary metric available for sensitivity studies - Relative number and types of hazards to be managed.*
- **Rationale:**
  - Safety is primarily an implementation issue, related to regulation, design, construction and operation of facilities. The types of hazards and the relative challenge to manage them is one of the few things that inform on safety at the fuel cycle level. The number of hazards informs on the complexity of safety compliance (but not directly on safety).
- **Information to address the metric:**
  - Potential hazards in fuel cycles will be identified in a standardized framework. Common fuel cycle features that make safety implementation more or less challenging will be identified for application to Evaluation Groups with those features. Unique fuel cycle features will be assessed as needed by the EST.
  - The EST, working with FCO staff and other campaigns as needed - will determine the Evaluation Group 'Relative Challenge for Safety Implementation'.

Criterion – Financial Risk and Economics

- **Financial Risk and Economics** – The economics (cost factors) of the mature deployed system, including siting, construction, and operation of facilities, including consideration of the financial risk.
- **About this Criterion:** The issue of nuclear energy economics is typically comprised of a number of costs and financial risks. However, many of the issues are technology, design and implementation specific. At the fuel cycle level, the primary indicator of economics is the estimated cost of electricity (or other energy product) produced.
- **The key economics question at the fuel cycle level is:**
  – Is it likely to be economically attractive?

Financial Risk and Economics Metrics

- **What is Included:** This criterion focuses on the economics of a fully deployed fuel cycle including siting, construction, and operation of facilities. Financial risk can be represented as an opportunity cost.
- **What is Not Included:** Technology or design details are excluded to the extent practicable (although representative technologies may be used for calculation). It does not include development or deployment risk (separate criterion). (Neither criterion addresses specific commercial deployment risk factors such as first-of-a-kind (FOAK) cost – which is deployment detail specific.)
- **Assumptions:**
  - This metric is not predicated on any specific size of the nuclear energy enterprise.
  - All technologies have been matured, and all facilities are deployed and retired repeatedly based on facility lifetime.
  - The financial risk involved with a fuel cycle option may be represented in the levelized cost of electricity (LCAE) through the use of a risk adjusted opportunity cost of capital, or discount rate.

Financial Risk and Economics Metrics

- **Metric (1):**
  - Levelized Cost of Electricity at Equilibrium (LCAE)
- **Rationale:**
  - Cost of electricity reflects the basic question about energy technologies, including nuclear.
  - This metric addresses both financial risk and economics and takes into account multiple economic factors, including the cost of construction, operation and decommissioning/closure of each type of facility needed for the nuclear energy system, in proper ratio for the mass flows of the system to be in balance. Where feasible, it also accounts for capital investments and the time value of money over the life cycle of each mine, mill, plant, reactor, storage and disposal facility while considering all of the related activities to be occurring simultaneously as needed for the equilibrium fuel cycle option screening. The financial risk involved with a fuel cycle option is included in the LCAE metric through the use of a risk adjusted opportunity cost of capital, or discount rate.

Financial Risk and Economics Metrics

- **Information to address the metric:**
  - The calculations of LCAE for each representative fuel cycle option will be performed by the FCO campaign prior to the nuclear fuel cycle evaluation and screening.
  - Each expense and revenue stream is discounted to an arbitrary point in time, typically the beginning of construction or irradiation, using a discount rate that reflects the financial risk of the project under equilibrium conditions.
    - *by means of an appropriate discount rate, the LCAE metric addresses both the "financial risk" and "economic" aspects of the high-level criterion*
  - Cost uncertainties are represented in a range.

Criterion – Environmental Impact

- **Environmental Impact** – The impact to the environment from all activities related to the civilian nuclear energy system.
- **About this Criterion:** There are a wide variety of issues commonly included in environmental evaluations of complex systems (EIS, EA). However, many of these issues are more specifically relevant to other high-level criteria. Others are technology, design and implementation specific and do not inform at the fuel cycle level. Such details will be important in the future to advise implementation decisions.
- **Key questions about environmental impacts may be summarized:**
  - What resources are used?
  - What emissions are released?

Environmental Impact Metrics

- **What is Included:** This criterion addresses consumption of environmental resources and emissions to the environment.
- **What is Not Included:** It does not address cost, operational safety or radioactive waste management – as these are addressed in other criteria.
- **Assumptions:**
  - To evaluate environmental impacts at the fuel cycle level, it is not relevant to focus on implementation details such as technology, facility design, location, etc. These will be important in future decisions on technology implementation pathway.

Environmental Impact Metrics

- **Metrics (5):**
  - Land Use per unit of energy production *(km^2/GWe-yr)*
  - Water Use per unit of energy production *(ML//GWe-yr)*
  - Radiological impact - total estimated worker dose per unit of energy production (Person-mSv/GWe-yr)
  - Chemical impact - chemical hazard index per unit of energy production *(Hazard Index(HI)/ GWe-yr)*
  - Carbon impact - CO_2 released per unit of energy production *(Mt/GWe-yr)*
- **Rationale:**
  - These metrics focus on what is used from the environment, and what is released into the environment. Most emissions will be regulated, and compliance becomes a cost issue.

Environmental Impact Metrics

- **Information to address the metric:**
  - Data are available for representative fuel cycle components, but not for all the variations of advanced fuel cycles that have never been built (or even designed).
  - Methodology used for representative fuel cycle components (such as ‘front-end’) will be extrapolated by FCO staff working with EST, other campaigns as appropriate, and industry as available. Identify potentially differentiating features of Evaluation Groups and provide guidelines on relative value versus the reference. EST will apply this guidance with expert judgment to fill data gaps as needed.

Criterion – Resource Utilization

- **Resource Utilization** – The natural fuel resources required per unit of power production from the civilian nuclear energy system.
- **About this Criterion:** In the context of nuclear energy and the nuclear fuel cycle, the issue of 'resource utilization' usually refers to the the availability of nuclear fuel resources to support the large-scale and long-term use of nuclear energy. While there are other resources used by a fuel cycle, these are more appropriately considered under 'environmental impacts'. This addresses the utilization, not the ultimate resource 'supply'.
- **Key questions about nuclear resource utilization may be summarized:**
  - How efficiently does a fuel cycle use fissionable material?

Resource Utilization Metrics

- **What is Included:** This criterion addresses the efficiency of utilization of natural fissionable resource material – uranium and thorium.
- **What is Not Included:** It does not address other resources, cost, operational safety or radioactive waste management – as these are addressed in other criteria. The amount of nuclear fuel resource available is not considered.
- **Assumptions:**
  - This metric is not predicated on any specific size of the nuclear energy enterprise.
  - Fuel resource utilization can be addressed at the fuel cycle level as the efficiency of resource use. It is not relevant to focus on implementation details such as technologies for resource extraction, estimated resource quantities, etc. These will be important in future decisions on technology implementation pathway.

Resource Utilization Metrics

- **Metrics (2):**
  - Natural uranium required per unit of energy production (*t/GWe-yr)*
  - Natural thorium required per unit of energy production (*t/GWe-yr)*
- **Rationale:**
  - These metrics focus on how efficiently a fuel cycle utilizes fuel resources.
- **Information to address the metric:**
  - Fuel material requirements will be calculated for the representative fuel cycle material flow as well as the electric energy (or equivalent) produced.
  - The metric will be scored as a ratio to the reference case.

Criterion – Development and Deployment Risk

- **Development and Deployment Risk** – The challenge of bringing to maturity the required technologies for a civilian nuclear energy system, including the time and cost required for successful research and development, and the ability to deploy licensable systems.
- **About this Criterion:** In considering nuclear fuel cycles, it is clear that they vary in technical maturity, in the effort needed to bring them to maturity, and the ultimate confidence that they can be matured and deployed. While many of the issues are dependent on the specific technologies, there are fuel cycle level requirements for enabling technology that can be used to assess the relative challenges for development and deployment.
- **Key questions about development and deployment risk may be summarized:**
  - How mature are the required technologies?
  - How much effort is needed to bring them to maturity?
  - What are challenges to deployment?

Development and Deployment Risk Metrics

- **What is Included:** This criterion addresses the current readiness of technologies needed for a fuel cycle, as well as the comparative challenge to bring them to deployment.
- **What is Not Included:** It does not address costs beyond development to commercial availability. It does not address specific commercial deployment risk factors such as FOAK cost – which are deployment detail specific.
- **Assumptions:**
  - A commonly used metric for technology maturity is the 'Technology Readiness Level' (TRL). While this is useful for comparing current maturity, it does not address the challenge needed to improve maturity to a deployable level.
  - A more comprehensive assessment is a Technology Readiness Assessment (TRA) that provides estimates of development time and cost. This comprises three steps:
    - *Identifying the Critical Technology Elements (CTEs)*
    - *Assessing the Technology Readiness Level (TRL)*
    - *Developing a Technology Maturation Plan (TMP)*
  - The extent of use of currently existing infrastructure, and the existence of an applicable regulatory structure, help to inform on the relative ease of deployment.

Development and Deployment Risk Metrics

- **Metrics (4):**
  - Development time
  - Development cost
  - Compatibility with the existing infrastructure
  - Existence of NRC regulations for the fuel cycle and familiarity with licensing

- **Rationale:**
  - The development risk is the likelihood that the technologies required to implement a fuel cycle would be successfully developed given sufficient time and resources.
    - When considering fuel cycles and the evaluation groups, the current status of the potential supporting technologies needs to be considered to inform on the level of R&D effort, both time and cost, that would be needed to produce a specific example of the fuel cycle.
  - The potential that advanced technologies will never become commercially viable is addressed via a ‘worst case’ score for development time and cost of “Unknown – potentially unlimited” for any technologies where sufficient research has not been conducted to provide confidence of eventual development and deployment success.

Development and Deployment Risk Metrics

- **Information to address the metric:**
  - The CTEs and TRLs will be estimated for each fuel cycle and used as the basis for evaluating the following metrics.
  - The development risk metrics
    - Development time – estimated time for increasing the TRL of a supporting technology from the current level to TRL = 6
    - Development cost – estimated cost for increasing the TRL of a supporting technology from the current level to TRL = 6
    - Compatibility with existing infrastructure (for both development and deployment) as measured by the amount of existing or new technology required, including the number of new industrial scale facilities required
    - Existence of regulations and NRC regulatory experience with each part of the fuel cycle, e.g., reprocessing, reactors other than LWRs, subcritical systems, extended storage, etc.; and NRC familiarity with reviewing and licensing such facilities.

Criterion – Institutional Issues

- **Institutional Issues** – The availability or ability to create the supporting infrastructure to deploy a civilian nuclear energy system, including the industrial infrastructure, qualified personnel, and the existence of regulations for licensing.

- **About this Criterion:** Institutional issues are associated with delays and risks from the potential large group of stakeholders (their concerns and constraints) and the ability to deliver the infrastructure elements of a given fuel cycle or associated technology. The list of stakeholders with regards to the use of nuclear energy is large and diverse, with the main ones for the fuel cycle evaluation and screening being investors, utilities and industry, government, and regulators. There is similarity in this criterion with the issues related to Deployment Risk.

Institutional Issues Metrics

- **What is Included:** This criterion addresses the readiness of institutional stakeholders to accept a fuel cycle and the technologies that implement it.
- **What is Not Included:** It does not address policy or economic issues.
- **Assumptions:**
  - This criteria has substantial overlap (but is not identical to) deployment risk. It addresses questions related to the required supporting infrastructure to develop and deploy a civilian nuclear energy system, including the availability of industrial infrastructure, qualified personnel, transportation needs, and the existence of regulations for licensing.

Institutional Issues Metrics

- **Metrics (2):**
  - Compatibility with the existing infrastructure
  - Existence of NRC regulations for the fuel cycle and familiarity with licensing
- **Rationale:**
  - Existing industrial infrastructure correlates with prior acceptance of implementation stakeholder to use similar technologies. Existing regulatory infrastructure correlates with governmental (and by implication – social) acceptance of similar technologies.
- **Information to address the metric:**
  - The CTEs and TRLs will be estimated for each fuel cycle and used as the basis for evaluating the following metrics
  - Institutional risk metrics are determined by:
    - Compatibility with existing infrastructure (for both development and deployment) as measured by the amount of existing or new technology required, including the number of new industrial scale facilities required
    - Existence of regulations and NRC regulatory experience with each part of the fuel cycle, e.g., reprocessing, reactors other than LWRs, subcritical systems, extended storage, etc., and NRC familiarity with reviewing and licensing such facilities.

Draft Metrics Summary

- Nuclear Waste Management (5)
  - Mass of SNF+HLW disposed per energy generated
  - Activity of SNF+HLW (@100 years) per energy generated
  - Activity of SNF+HLW (@100K years) per energy generated
  - Mass of DU/RU disposed per energy generated
  - Volume of LLW per energy generated
- Proliferation Risk (3)
  - Maximum FOM_1 (nominal fuel cycle material)
  - Maximum FOM_1 (material with mis-use technology included in the fuel cycle)
  - Maximum FOM_1 (material with clandestine use of any technology)
- Nuclear Material Security (1)
  - Maximum FOM_1 (nominal fuel cycle material)
- Safety (1)
  - Relative Safety Management Challenge for all facilities and processes
- Financial Risk and Economics (1)
  - Levelized Cost of Electricity at Equilibrium
- Environmental Impact (5)
  - Land Use per unit of energy production
  - Water Use per unit of energy production
  - Radiological impact - total estimated worker dose per unit of energy production
  - Chemical impact - chemical hazard index per unit of energy production
  - Carbon impact - CO_2 released per unit of energy production
- Resource Utilization (2)
  - Natural Uranium required per unit of energy production
  - Natural Thorium required per unit of energy production
- Development and Deployment Risk (4)
  - Development time
  - Development cost
  - Compatibility with the existing infrastructure
  - Existence of NRC regulations for the fuel cycle and familiarity with licensing
- Institutional Issues (2)
  - Compatibility with the existing infrastructure
  - Existence of NRC regulations for the fuel cycle and familiarity with licensing